Media Preconditioning for Perpendicular Recording in Disk Drives

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Field of the Invention

The present invention related to magnetic recording and in particular to magnetic recording of data in data storage devices.

Background of the Invention

Storage devices such as disk drive utilize a magnetic disk and transducer head for magnetically recording data and reading data from concentric tracks on the magnetic disk. In longitudinal recording of data, information is magnetized in transitions recorded horizontally, parallel to the surface of the magnetic disk. In perpendicular recording, the magnetic transitions are perpendicular to the disk surface, allowing storage of more data. In longitudinal recording at high areal density the recorded data degrades overtime as indicated by degradation in the amplitude of the readback signal. Perpendicular recording can also suffer from this effect.

In perpendicular recording, DC band erase has a large impact on the Bit Error Rate (BER) performance of the disk drive (BER is a way to measure quality of data retrieved back after storage, represented by the number of bits in error divided by the number of bits transferred). In DC erase an essentially constant current is applied to the write head to erase data stored on the disk.

In perpendicular/vertical recording the magnetic transition is perpendicular to the disk surface. The write head has two poles, wherein one of the two poles has a larger dimension than the other, such that in DC erase for a wide range of tracks, the DC field couples into one of the two poles. When writing data, the head has a bias due to flux from the other tracks into the write pole. The bubble, where the data is written to the disk, either expands or contracts because of the magnetic field.

The reason for the change in BER is due to the transition shift caused by the magnetic field from the adjacent area of the disk coupling into the write head while it is writing. This effect is substantial for perpendicular recording because the soft under-layer of magnetic layer allows the magnetic flux to couple efficiently into the write head. The effect is negligible for longitudinal recording because there is no soft underlayer to help with collecting magnetic flux from a large area. In longitudinal recording, the medium is DC erased after it is assembled into the disk drive, which degrades the disk drive performance for perpendicular recording.

There is, therefore, a need for method and apparatus that eliminates the effect of the adjacent medium magnetic field on the data track written in perpendicular.

Brief Summary of the Invention

The present invention satisfies these needs. For perpendicular recording, media preconditioning plays a major role in determining the drive servo and Bit Error Rate (BER) performances. This effect is due to the medium magnetic field from the adjacent area which can couple into the write head while the data track is being written. The present invention provides a procedure to minimize the effect of adjacent medium magnetic field on the written track, wherein the procedure include preconditioning the media by AC erasing the media.

In one embodiment the present invention provides a method of demagnetizing magnetic media for recording data in a data storage device, including the steps of placing the magnetic media in a magnetic field at a first strength level; and gradually reducing the magnetic field to a second strength level to essentially eliminate net magnetization in the magnetic media. Another embodiment of a method of demagnetizing magnetic media for recording data in a data storage device, comprises the steps of: determining a recording frequency for writing on the magnetic media with a transducer head, at which the amplitude of the transducer head readback signal from said portion of the magnetic media is essentially at noise level; and writing on the magnetic media at substantially said recording frequency, to substantially eliminate net magnetization in the magnetic media.

Brief Description of the Drawings

These and other features, aspects and advantages of the present invention will become understood with reference to the following description, appended claims and accompanying figures where:

FIGs. 1A-C show a first example method of using electromagnets to erase disks according to the present invention;

FIG. 1D shows an example flowchart of steps of erasing disk(s) according to the present invention;

FIGs. 2A-B show a second example method of using electromagnets to erase disks according to the present invention;

FIG. 2C shows an example block diagram of apparatus for erasing heads according to the present invention;

FIG. 3A shows example plots illustrating the increase in BER for the readback signal from data recorded on data tracks when conventional process of band DC erase is used before writing data tracks compared to AC erase according to the present invention;

FIG. 3B shows example plots illustrating the transition shift with respect to

the width of the erase band for convention DC erase compared to AC erase according to the present invention;

FIG. 4A shows an example flowchart of another embodiment of a method of erasing disks according to the present invention;

FIG. 4B shows a simplified block diagram of an example a disk drive in which an embodiment of the present invention can be implemented;

FIG. 4C shows an example diagram of head flux due to AC bias current according to the present invention;

FIG. 5 flowchart of another embodiment of the method of present invention;

FIG. 6A shows an example plot illustrating a timing histogram of differentiated data written after a conventional DC band erase;

FIG. 6B shows readback signal measurement for data track written on as-received media after a disk sputtering process without any net magnetization, by turning off write current in regions that are normally DC erased, according to the present invention;

FIG. 7A shows an example flowchart of a method of demagnetizing disk(s) according to the present invention by DC erasing with alternate polarity of the DC erase current each time the head is stepped;

FIGs. 7B-C show example diagrams of head flux due to +DC and -DC alternating polarity bias current of the embodiment in FIG. 7A;

FIG. 7D shows example plot illustrating readback signal of data written on media preconditioned by DC erasing with alternate polarity on adjacent tracks, according to the method in FIG. 7A.

Detailed Description of the Invention

Conventional DC erase methods degrade the bit error rate (BER) in readback signal (e.g., 2 orders of magnitude increase) from data recorded on data tracks after such DC erase. This is because the magnetic field from the DC erased regions couple into the head writer element, resulting in transition shifts. Coupling of the magnetic field from the DC erased regions into the head

enhances one polarity of writing and degrades the other with the result that either positive or negative bit cells last longer than the other polarity. This timing asymmetry degrades the BER, and has a substantial negative impact on the BER performance of disk drives because many parts of the medium in servo wedges and unused parts of the data zone are conventionally DC erased.

Example methods of eliminating the above effect according to the present invention, include performing AC erase of data tracks before writing data.

FIGs. 1-2 show two different example apparatus 10 and methods, (Configuration 1 and Configuration 2, respectively), to perform AC bulk erase according to an aspect of the present invention. Referring to FIGs. 1A-C, according to example steps in flowchart of FIG. 1D, two U-shaped magnets 12 (e.g., electromagnets) are used wherein the magnets 12 are positioned on the opposite sides of a disk 14, covering at least a radial section of the disk 14 as shown in FIGs. 1A-B (step 11). As shown in FIG. 1B, the poles 12a of the magnet 12 are either moved from inner diameter (ID) to outer diameter (OD) to cover the disk surface, shown by broken arrow in FIG. 1B, or the magnet poles 12a are wide enough to cover the entire width of the disk surface (i.e., from the ID to the OD) as shown in FIG. 1C.

Referring to FIGs. 2A-B, in Configuration 2, two U-shaped magnets 12 are used wherein the disk 14 is positioned in a gap 12b of the magnets 12, and the magnets 12 are positioned about 180° apart, as shown in side and top views in FIGs. 2A-B, respectively.

In both configurations, AC erase of data tracks is performed by: powering the electromagnets 12 to generate an initial high strength magnetic field 12c between the magnets 12 (step 13), rotating the disk 14 (shown by curved arrow in FIG. 1C) while the magnetic field generated by the electromagnets 12 is slowly reduced to a lower level (e.g., zero) from the high starting field strength (about 1

KGauss to 100 KGauss) based on coercivity of the magnetic media on the disk 14 (step 15). Data can then be written on the disks 14 (step 17). As such, as shown by example in block diagram of the apparatus 10 in FIG. 2C, a power source 16 (e.g., programmable direct current source) is applied to the electro-magnets 12, wherein the amplitude of the current applied to the magnets 12 can be varied (e.g., continuously or stepwise) from a high current for a starting magnetic field to essentially zero current for an essentially non-existence magnetic field. The starting field strength of the electromagnet is selected so that it is much higher than the coercivity (Hc) of the magnetic media on disk surfaces.

The rate of reduction of magnetic field 12c depends on the speed of rotation of the disk 14. In one example, the magnetic field 12c is decremented to zero, approximately one decrement per revolution of the disk 14. The amount of time elapsed for each decrement is about the same or marginally longer than the time elapsed for a revolution of the disk. For example, if the disk rotates at 10 msec per revolution, then the magnetic field is decremented in more than 10 msec. The faster the speed of rotation, the faster the rate of reduction of the magnetic field. In another example, the amount of time elapsed for each decrement is more than the time elapsed for a revolution of the disk. For example, if the disk 14 rotates at 10 msec per revolution, then the magnetic field is decremented by one steps in more e.g. 20 msec, etc.

As shown in FIG. 2C, the AC erase is performed by placing one or more disks 14 in the eraser apparatus 10 further including a spin motor 18 for spinning/rotating disks 14, wherein the electromagnets 12 are positioned proximate the disks 14 as shown in FIGs. 1A-C and 2A-B. A controller 20 controls the level of e.g. current generated by the power source 16, and thereby controls the magnetic field generated by the magnets 12. Optionally a monitor 19 monitors rotational speed of the disks 14 whereby the controller 20 decrements the magnetic field to zero based on the rotational speed of the disks 14. In another version a monitor is not necessary, wherein based on a

predetermined speed of rotation of the disks 14 the controller 20 decrements the magnetic field to zero. The apparatus 10 can further include a housing 21 for housing said components to erase disks 14 placed therein.

The Configurations 1, 2 above can be modified to erase multiple disks 14 at the same time. The distance between the magnets 12 and surfaces of disks 14 (e.g., 1 or 2 millimeter) is such as to provide magnetic fields perpendicular to the surface of the disk 14. After the above AC erase procedure, the disks 14 are assembled in disk drives for customer use.

Referring to FIG. 3A, example comparative plots illustrate bit error rate (BER) in readback signal for AC erase 22 according to the present invention, and degradation (e.g., 2 orders of magnitude increase) in BER for the readback signal from data recorded on data tracks when conventional process of only +DC band erase 24 or only -DC band erase 26, is used before writing data tracks. This is because the magnetic field from the DC erased regions couple into the head writer element, resulting in transition shifts. FIG. 3B shows example comparative plots illustrating the transition shift with respect to the width of the erase band using AC erase 28 according to the present invention, and using conventional +DC and -DC erase 30, 32. Coupling of the magnetic field from the DC erased regions into the head enhances one polarity of writing and degrades the other with the result that either positive or negative bit cells last longer than the other polarity. This timing asymmetry degrades the BER, and has a substantial negative impact on the BER performance of disk drives because many parts of the medium in servo wedges and unused parts of the data zone are conventionally DC erased.

Referring to example steps in FIG. 4A, in another aspect of the present invention, the AC erase method includes AC erasing the disks (i.e., recording medium) in spin-stand or disk drive, at a frequency (F) determined by the following steps:

(a) Selecting e.g. the outer diameter (OD) of the disk as the test track 23 (e.g., FIG. 4B) (step 34) -- in other versions other test tracks such as inner diameter (ID), middle diameter (MD,, etc. can be selected;

(b) Setting the write clock/frequency to a nominal low frequency (e.g., about 50 to100 MHz) (steep 36);

(c) AC writing the test track at a nominal write data clock frequency (frequency of bits transitions) with write element of a transducer head 25 (e.g., FIG. 4B) (step 38);

(d) Reading back from the test track using read element of a head 25 after setting for write-read offset (because of offset distance between read and write elements in a head, after a write operation, the radial position of the head is adjusted by the offset distance to place read element over the test track to read), and measuring the amplitude of the read back signal (step 40);

(e) Increasing the write clock frequency and repeating steps 38, 40, until the amplitude of the readback signal reduces to noise level (the amplitude does not change any more as the write clock increases) (steps 42, 44); and

(f) Noting the clock frequency (F) at which the readback signal amplitude becomes low and relatively constant, and performing AC erase at or above clock frequency F on all data tracks to be erased (step 46).

At the start of the above process for searching for the AC erase write frequency, the noise level may not be known. The noise level is observed toward the end of the test at high frequency when the read signal amplitude is relatively constant as the write frequency is increased, indicating the readback signal amplitude is same as the noise level in the system. In the description herein, "noise level" is the level at which the averaged amplitude of the read signal remains relatively constant as write frequency increases.

The above steps can be performed in a spin-stand apparatus (test apparatus typically used to test head and media at the component level before

assembled in disk drives), or in disk drives (e.g., FIG. 4B) after disks 14 are assembled therein.

Referring to FIG. 4B, a simplified block diagram of an example disk drive 100 in which an embodiment of the present invention can be implemented. The disk drive 100 comprises storage medium such as data disks 14, and a disk drive controller 114 for interfacing with a host and controlling disk drive operations including data transfer to and from storage media 14, therein. The disk drive 100 further includes a head structure 116 including one or more heads 25 (each head 25 including a read element 25a and a write element 25b) moved by a support arm of an actuator assembly 120 via a VCM 122 across tracks of one or more disks 14 for data storage and data retrieval, and tracking to maintain the head over a target position.

Each disk 14 includes a servo pattern including multiple tracks 23 for data storage, on a recording surface thereof. The disk drive 100 further includes a preamplifier 124 for amplifying the read and write signals from and to the disks 14, respectively, and a read/write channel 126 for encoding and decoding data between user information and data written on disks 14. The channel 126 also decodes servo track number and converts servo burst amplitudes into digital values. The disk drive 100 further includes a power driver IC 128 for driving the actuator 120 and a spindle motor 130 for rotating the disks 14. In one example embodiment, the controller 114 includes a memory 132, microcontroller (e.g., microprocessor) 134 for controlling head bias current, and a drive control 136 for general control of the components of the disk drive 100. The disk drive 100 can further include memory 142 for storing other program instructions or data. The memory 142 can include RAM and/or non-volatile (NV) memory such as EEPROM, ROM, etc.

The disk drive firmware 114 or memory 142 can include an AC erase function according to the above steps. Preferably the AC erase is performed

before any writing is performed on the disks 14 (including writing servo patterns in servowrite, and writing any user data).

After the disk drive 100 is assembled, AC band erase at the clock frequency (F) determined by the above procedure is programmed therein. The medium AC erase preconditioning according to the above steps improves both servo and data BER performances compared to conventional DC erase.

Preferably, the above steps of FIG. 4A are performed on a head 25 and disk 14 that are being used for the disk drive product 100. The clock frequency (F) can be scaled up or down if necessary to change the spindle 130 speed (RPM) for AC erase as long as the linear density of data is kept essentially constant. The AC erase is preferably performed on the area of the disk that is intended for data storage. Once the frequency F is determined for a disk drive 100, it can be used to AC erase multiple disk drives 100.

FIG. 4C shows an example diagram of head flux 150 from a head 25 due to AC erase according to the present invention. For the AC Erase precondition case, when data is written to the tracks, the magnetic field 150 of the write head 25b is denoted by two down-arrows and two curved-arrows (magnetic bubbles). When the disk 14 (medium) is preconditioned with +DC Erase only or with - DC Erase only, the magnetic bubbles are either increased or decreased (depending on the direction of the write current) causing the written transition to expand or contract (number of curved arrows increase or decrease, respectively) and in turn causing transition shift.

According to another aspect of the present invention, an alternative method for demagnetizing the medium 14 includes the steps of turning off head write current in regions that are normally DC erased (this preserves the demagnetized condition of the as-sputtered medium). As such, there is no DC erase of the disks 14 from the time the disks 14 are sputtered with magnetic

media, until they are installed into the disk drive 100 before servo patterns are written.

The conventional process of longitudinal recording includes DC erasing the data tracks of disks 14 in part or whole. One example of DC erase for part of the disk surface is performed during Write/Read offset measurements to determine the offset of the write and read element of the head. This embodiment of the method of the present invention ensures that the disks 14 are not DC erased, preserving the demagnetized condition of the as-sputtered magnetic medium on the surface of the disks 14. Referring to the example flowchart in FIG. 5, an embodiment of this method includes the steps of: sputtering the surfaces of disks 14 with magnetic media in a sputtering process (step 152); performing media test process without DC erasing the disks 14 (step 154); installing the disks 14 in disk drives 100 (step 156); and performing servo writing and test process without DC erase (step 158). This method ensure a demagnetized state for regions of the disks 14 that are conventionally DC erased, and essentially alleviates timing asymmetry.

An example plot in FIG. 6A shows a timing histogram of differentiated data written after a conventional DC band erase. Two peaks are clearly present corresponding to the different lengths of positive and negative bit cells, showing bit shifts and timing asymmetry. Another example plot in FIG. 6B shows the same measurement for a data track written on as-received media after a disk sputtering process without any net magnetization, by turning off write current in regions that are conventionally be DC erased. This preserves the demagnetized condition of the as-sputtered medium, whereby timing asymmetry is eliminated. As such, after magnetic media is deposited on a disk surface, providing demagnetized ("raw") medium (i.e., random magnetization) such that data can be recorded on the disk surface, servo and user data are recorded on the disk without a conventional DC erase step. In one example, such a raw disk 14 is

placed in a servowriter (not shown) or assembled in a disk drive 100 for writing data thereon, without a DC erase process.

Referring to example steps in FIG. 7A, another method of demagnetizing (e.g., erase) the medium according to the present invention includes DC erase of the unused regions, but with alternating the polarity of the DC erase current each time the head is stepped (i.e., moved radially, wherein in one example step size is smaller than the track pitch). In one version, the head 25 is moved to a first track of a disk surface region to be erased (step 160). The DC write current for the head is set (step 162), and the head DC writes on the current track at a first polarity (step 164). If other tracks remain to be erased (step 166), the head 25 is moved/stepped to the next track (step 168), polarity of head write/bias current is reversed (step 170), and the track is written (step 164). The above steps are repeated until the desired regions are erased.

FIGs. 7B-C show example diagrams of head flux 150 when the medium 14 is alternately +/- DC erased, respectively, with write element 25b of head 25 according to the example method of FIG. 7A, wherein the +Bdc field cancels the -Bdc field and the net effect is similar to AC Erase.

In one example, amplitude of the head current is about 10 to 50 mA. This method ensures a demagnetized state for regions of the disk that are conventionally DC erased, and essentially alleviate timing asymmetry. An example plot in FIG. 7D shows measurement of readback signal from data written on media 14 preconditioned by DC erasing with alternate polarity on adjacent tracks. The unused regions of the disk 14 are DC erased by alternating the polarity of the DC erase current each time the head is moved (e.g., step size smaller than the track pitch), whereby timing asymmetry is eliminated. The above examples show benefit of eliminating the net magnetization in unused portions of a perpendicular recording medium (e.g., 50Gb/in^2).

The present invention has been described in considerable detail with reference to certain preferred versions thereof; however, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.